STATUS OF THE SUPERCONDUCTING ECR ION SOURCE *VENUS*

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Abstract

A new, very high magnetic field superconducting ECR ion source, *VENUS*, is under development at the LBNL 88-Inch Cyclotron. It will boost the maximum energies and intensities for heavy ions from the cyclotron particularly for ions with mass greater than 60. It will also serve as R&D ion source for the proposed Rare Isotope Accelerator (RIA) project in the US, which requires up to 10 pμA of U^{30+}. The superconducting magnet structure consists of three solenoids and six racetrack coils with iron poles forming the sextupole. The coils are designed to generate a 4T axial mirror field at injection and 3T at extraction and a radial sextupole field of 2.4 T at the plasma chamber wall. Test results of the magnet coils, which exceeded design requirements with minimum training, are presented. The magnet assembly with its cryostat will be enclosed by an iron shield and therefore must be designed to withstand any possible forces between coils and iron, which can be as high as 35,000 kg-force. The low energy beam transport line (LEBT) and mass analyzing system of the ion source is designed to transport a proton-equivalent current of 25mA at 20kV extraction voltage. The design of the ion source and LEBT will be discussed.

1 INTRODUCTION

The superconducting ECR ion source (ECRIS) *VENUS*, whose R&D progress has been previously documented [1, 2], is presently beginning its construction phase. The *VENUS* project aims for following significant improvements for ECRIS:

1. Reach the highest magnetic fields so far obtained in an ECRIS to improve plasma confinement.
2. Utilize a commercially available 10kW-CW 28 GHz gyrotron amplifier to take advantage of the high magnetic fields and the large plasma volume.
3. Develop new clamping schemes for the superconducting coils in order to withstand the strong magnetic forces.
4. Use state of the art cryogenic equipment, utilizing cryocoolers and High Tc leads, to eliminate the need of a liquid-He filling system.

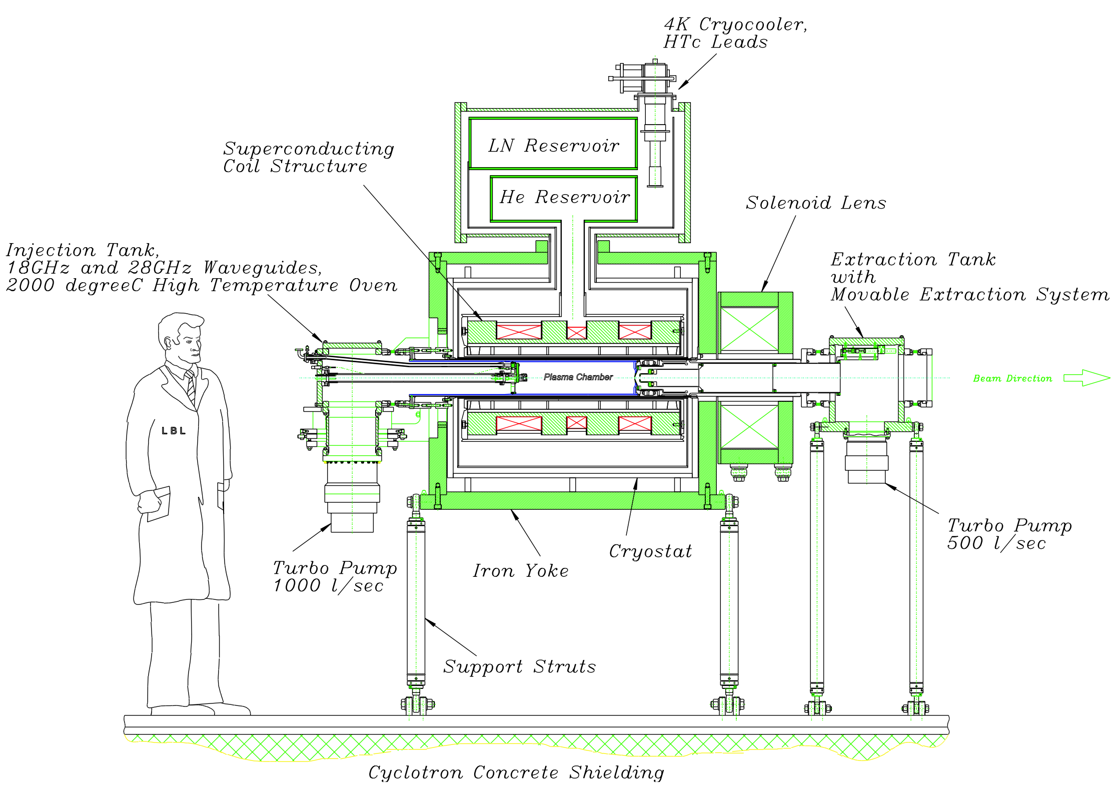

Figure 1: Section view of the *VENUS* ion source.

5. Develop a cold mass suspension system, which can withstand the strong magnetic forces that occur in ECRIS designs and simultaneously maintain a low heat leak to allow the use of cryocoolers.
6. Develop a miniature high-temperature oven (~2000 deg. C) to be axially inserted into the ion source.
7. Develop a thin walled aluminum plasma chamber, which allows sufficient cooling of the walls and maintains a maximum plasma volume.
8. Increase the electrical insulation capability of the source in order to facilitate operation at higher extraction voltages.
9. Develop a beam extraction and analyzing system, which can transport the higher expected beam intensities. The high magnetic field (up to 3 T) of the extraction region results in different focusing properties for different ions thus requiring a versatile transport system.

In order to demonstrate these technology advancements some VENUS design parameters are compared with the respective parameters of the two existing LBL ECR ion sources [3] in table 1.

Table 1: Comparison between LBNL ECR Ion Sources

	ECR	**AECR**	**VENUS**
Magnetic Field: Ampere-Turns	231,000	317,000	3,000,000
Magnetic Field: Peak Field	0.4 T	1.7 T	4 T
Microwave: Frequency	6.4 GHz	10 GHz + 14 GHz	18 GHz + 28 GHz
Microwave: Total Power	600 W	2,600 W	14,000 W
Extraction: High Voltage	10 kV	15 kV	30 kV

1 SOURCE DESIGN

Fig. 1 shows the mechanical layout of the VENUS ion source. The plasma chamber is made out of an aluminum tube with gun-drilled water cooling-channels. Aluminum provides a source of cold electrons for the plasma. This technique has been developed and tested on the LBNL AECR. In addition to the favorable secondary emission properties of the aluminum wall, which come from the formation of Al_2O_3 on the surface, the aluminum is very resistant to plasma etching. This reduces contamination in the plasma of ions from the wall. To further increase the vacuum cleanliness, the whole source and beamline are metal sealed.

Three off-axis microwave feeds as well as two ovens and a biased disk are inserted from the injection spool. We have developed a high temperature (>2000 deg. C) miniature oven, which fits through a 2-3/4" conflat flange. The oven is currently fabricated and will be first tested in the AECR source. The biased disk is star-shaped to terminate the plasma and still provide enough space for the waveguide and oven penetrations. The open space of the biased disk is the only vacuum-pumping opportunity for the plasma chamber. Taking into account the limited conductance of the injection tank a 1000 l/sec turbo pump will allow sufficient pumping of the plasma chamber.

During the first year of operation two 18 GHz CPI klystron amplifiers (VKU-7791A12) will provide up to 5 kW CW total microwave power at the amplifier output. In a later project phase, it is planned to upgrade *VENUS* with a 28 GHz CPI gyrotron (VGA8028) system, which can deliver 10kW CW total power. We expect that only such a microwave system will allow optimal use of the high magnetic field and the large plasma volume of *VENUS*.

Also shown in Fig. 1 are the end walls of the iron shielding-yoke, which is designed to reduce the magnetic stray-field outside the yoke to <50 Gauss. Such a low magnetic field is required – besides being a safety measure – by the cryocoolers and the HTc leads located in the cryogenic service tower above the magnet structure. The HTc leads, which minimize the cryostat heat leak, quench at a certain magnetic field level (depending on the lead current).

We are currently constructing the *VENUS* cryostat at WANG NMR Inc. in Livermore, CA, where all of the superconducting magnet coils were wound. The fabrication of the magnet structure was completed fall 1999. Its design was improved in several respects compared with a prototype magnet [2, 4]. It is mandatory to eliminate any possible movements of the superconducting coils in order to avoid quenching of the superconducting wires. As described in [2, 4] existing clamping schemes could not constrain the sextupole coils sufficiently. Therefore, we have developed a new method of clamping: Expandable bladders - consisting of two flat sheets of 0.25 mm stainless steel stacked together and welded on the edges – are inserted along and at the end of the sextupole coils. A 3 mm OD stainless steel tube is welded to each bladder through which fluid can pressurize the space between the two steel sheets. With the bladders in place, the sextupole assembly is heated to 65 deg. C. The azimuthal bladders are inflated to 10.4 MPa and the end bladder to 2.6 MPa with a liquid metal having a melting temperature of 47.2 deg. C. The alloy, Incaloy 117, has a very small volume change during solidification. This way, the coils are uniformly compressed azimuthally and radially.

The success of the new clamping scheme and other improvements was demonstrated during magnet tests of the superconducting coil assembly (axial and sextupole coils) in fall 1999 [4]. The sextupole coils reached more than 125% of the coil design current after only five training quenches when tested by itself. At maximum solenoid field, the sextupole coils reached more than 125% of the design field after four additional training quenches. (The solenoid coils experienced no quenches up to the power supply limits in a previous test.) In summary, the *VENUS* magnet system exceeds the design requirements by utilizing permanently inflated "expandable shims", thus providing the highest magnetic fields ever achieved in an ECR coil configuration.

Fabrication of the cryostat and source components will continue until end of this year. First beam tests are scheduled for summer 2000 after assembly of the beamline.

2 LOW ENERGY BEAM TRANSPORT

The effect of the high magnetic ion-source field (up to 3 T) on the ion beam extraction and matching to the beam line has been investigated in [2, 5]. The various charge states focus differently in the high magnetic field of a superconducting ECR ion source. This leads to typical emittance patterns, where each charge state is oriented differently in phase space. For the 88-Inch Cyclotron operation, the LEBT must be versatile enough to transport many different ion beams and charge states at varying extraction voltages.

The tuning flexibility of the existing LBL ECR beamlines comes from the insertion of a solenoid lens

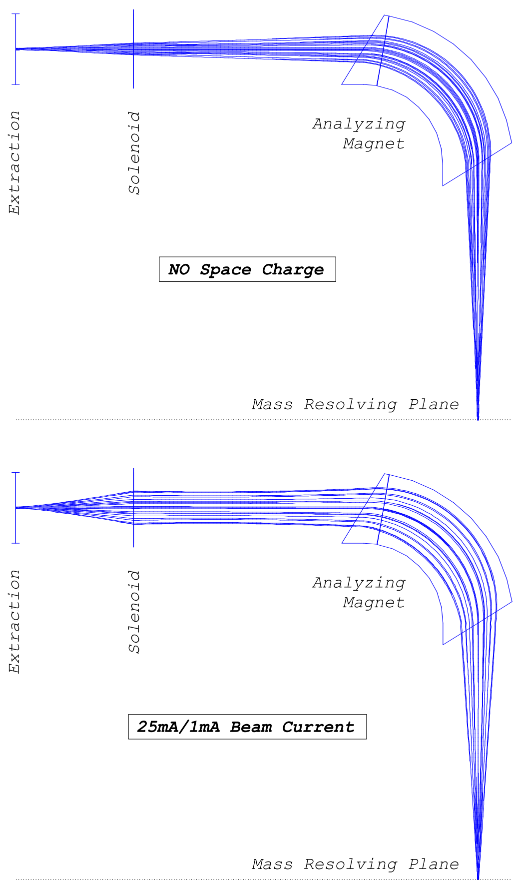

Figure 3: VENUS low energy beam transport simulation (GIOS) for different extracted beam currents (The second number refers to the current after the analyzing magnet).

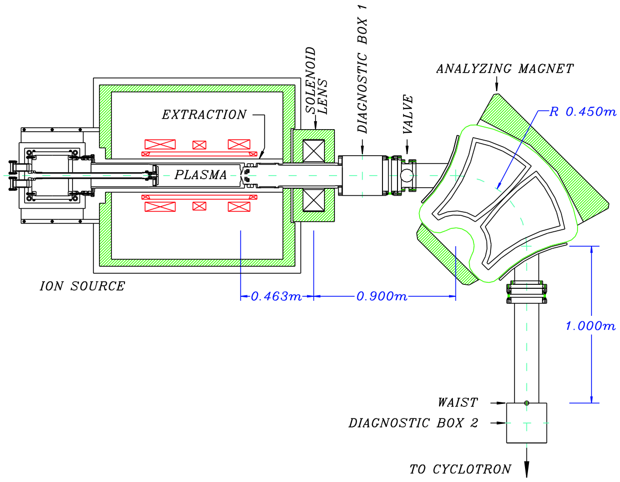

Figure 3: VENUS beamline layout.

between the extraction and the analyzing magnet. In this scheme the solenoid lens focuses the extracted beam to the first focal point of the analyzing magnet. Ion optics simulations show that a small waist in front of the analyzing magnet induces strong aberrations in high-space-charge ion beams. Further, the magnetic field of the solenoid lens must be more than one Tesla for the extraction voltages (up to 30 kV) considered for VENUS.

Therefore, we have decided to eliminate the waist in front of the analyzing magnet. Now the sole purpose of the solenoid lens is to adjust the angle of the beam going into the magnet (see Fig. 2 and 3). The actual beam diameter cannot be controlled with a single solenoid lens. Therefore, a sufficiently large magnet gap must be chosen to accommodate the highest anticipated beam intensities.

Such a multipurpose analyzing magnet is currently in design and will incorporate two quadrupole and two sextupole moments at the magnet edges and two more sextupole moments in the magnet center to compensate for higher order effects. 3D magnet calculations (Tosca 3D) are necessary to define the correct pole shape of the analyzing magnet. The resolution of the magnet will be m/Δm~100, its beam radius 45cm and its pole gap 22cm.

3 REFERENCES

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